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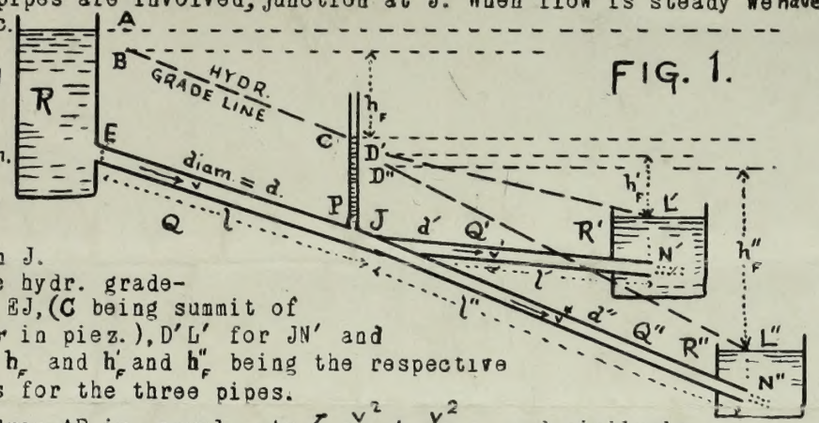
1. FRICTION-HEAD DIAGRAMS. BRANCHING PIPE. Reservoir R supplies R′ and R″. Three cylin. pipes are involved; junction at J. When flow is steady we have Q cub. ft. p. sec. in main pipe = sum of Q′ and Q″ in other two pipes. Notation as shown. Conceive an open piezom. P inserted just up-stream from J. Then BC is the hydr. grade-line for pipe EJ, (C being summit of standing water in piez.), D′L′ for JN′ and D″L″ for JN″; h_F and h'_F and h''_F being the respective friction-heads for the three pipes.



The vertical drop AB is equal to $\zeta_E \frac{v^2}{2g} + \frac{v^2}{2g}$; and similarly vert. drop CD′ $= \zeta' \frac{v'^2}{2g} + \left[\frac{v'^2}{2g} - \frac{v^2}{2g}\right]$; and CD″ $= \zeta'' \frac{v''^2}{2g} + \left[\frac{v''^2}{2g} - \frac{v^2}{2g}\right]$;

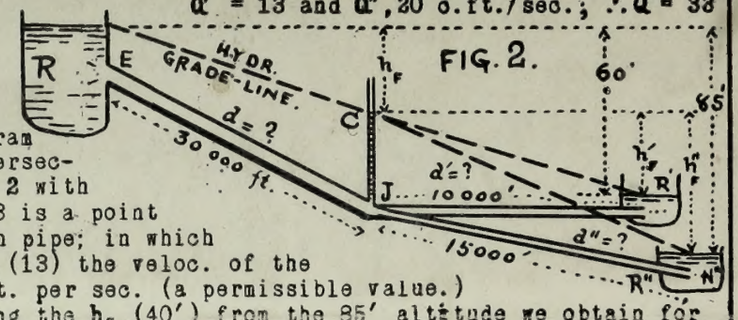
where $\zeta' v'^2 \div 2g$ and $\zeta'' v''^2 \div 2g$ are losses of head due to change of sectional area (if abrupt) and to elbow resistance. The depths L′N′ and L″N″ at which the pipes discharge under water are immaterial. There are NO NOZZLES at N′ and N″; that is, the jets have same sectional area and veloc. as the water in respective pipes. IN MOST CASES IN PRACTICE the velocities in systems of pipes are rarely over 10 ft. per sec. and the pipes are quite long, so that, in treating a problem like the above it is sufficiently accurate to neglect the small "drops" AB, CD′ and C D″, and consider that the whole drop from surface of R to that of R′ is = the sum of the two friction-hds h_F and h'_F; (also, whole drop from R to R″ = $h_F + h''_F$.)

Pages 3 and 4 of this leaflet give diagrams from which friction-heads for a pipe of 1000′ length, if veloc. v or discharge Q is given, can be obtained. (Clean iron pipe, not-riveted). For v = 0, of course h_F = 0.)

EXAMPLE I. (Fig. 2) Determine proper diameters for the three pipes, given Q = 13 and Q″ = 20 cub. ft. per sec. (so that Q must = 33 c. ft/sec.)

SOLUTION. (Lengths and altitudes being given as shown; clean iron pipe) We are at liberty to assume one of the diameters; or the friction-head, h_F of the main pipe; say the latter. Take h_F = 40 ft. A steady flow is to take place in pipe EJ of 33 c. ft. p. sec. and the friction-head is to be at rate of (40÷30=) 1.33′ per 1000′ of length. In the diagram on p. 4 we note that the vertical line for 1.33 (interpolating) intersects the horiz. line for Q = 33 in a point corresponding to a diam. of 38 in. (among the lines sloping up to the right) while among the other inclined lines (sloping down to the right) we find that with this discharge the velocity of the water in this 38-inch pipe would be 4.1 ft. per sec. (which is not extreme) Deducting the assumed h_F (40′) from the altitude 60′, we find the corresponding value of h'_F to be 20 ft.; i.e., at the rate of (20÷10=) 2 ft. per 1000′ length of pipe. From same diagram we note that the intersection of the vertical 2 with the horiz. for Q = 13 is a point calling for a 25-inch pipe; in which with this value of Q (13) the veloc. of the water would be 3.8 ft. per sec. (a permissible value.)

Q′ = 13 and Q″, 20 c. ft./sec.; ∴ Q = 33



Similarly, deducting the h_F (40′) from the 85′ altitude we obtain for the h''_F of the other branch-pipe, 45′; which is at the rate of (45÷15 =) 3 ft. friction-head per 1000′ of length; for which, with Q = 20, the diagram gives a diam. of 27.5 in. for pipe JN″ with a veloc. = 5′/sec.

If h_F had been assumed somewhat > than 40′ a smaller diam. would have resulted for the main pipe, EJ, with a higher veloc. in it than before; but larger diams., and smaller velocs., in the two branch-pipes. Results should be sought involving the LEAST COST, with sufficient velocs. (above 2′/sec.) to prevent the deposit of silt.

The diagrams are for CLEAN CAST IRON PIPES; and also wrought-iron pipes from ½ inch to 6 in. diameter, such as can be manufactured WITHOUT RIVETING. For riveted iron and steel pipe, see p. 235 of TURNEAURE AND RUSSELL'S PUBLIC WATER SUPPLIES (a recent and valuable book).

2. EFFECT OF AGE. With increasing age of service cast iron pipes are liable to become corroded and tuberculated (if originally tar-coated this action may be much retarded) which diminishes the discharge under the same head; (both from increased roughness and diminished sectional area.) Mr. E. B. Weston recommends that for pipes of cast iron the friction-head for a given Q be taken as 16 per cent. greater than when the pipe is new and clean, for each five years of age. For example, for an age of 15 years take as the friction-head for a given flow Q, and per 1000′ of length, the value obtained by multiplying the result given by the diagram by 1.48.

3. VARIATIONS FROM ABOVE PROBLEM. In the above example the diameters were the quantities sought; but if the diameters were given and the rates of flow that would occur in the respective pipes were to be determined, proceed thus:— Assume a trial value for Q and find from diagram the friction-head per 1000′ length of pipe of given diameter d, thence the value of h_F for actual length of EJ. Values of h'_F and h''_F corresponding to h_F are now noted and corresponding values of Q′ and Q″ found from the diagram for respective diameters d′ and d″. The sum Q′ + Q″ should be equal to Q. If such is not the case as a result of the first trial, assume a new value for Q; and so on, until the necessary equality is obtained.

In the above it is supposed that water flows into R′ and R″, and out of R; but if R′ is at a sufficient elevation, or if pipe EJ is small in diameter, water may flow out of R′, as well as out of R. In such a case the summit C would be lower than the surface in R′, and Q + Q′ = Q″.

Similar principles and methods apply to any system or net-work of pipes

Friction-Head Diagrams for Flow of Water in Clean Iron Pipes (Non-Riveted); by I. P. Church.

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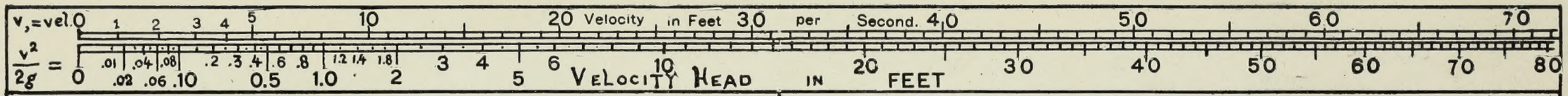
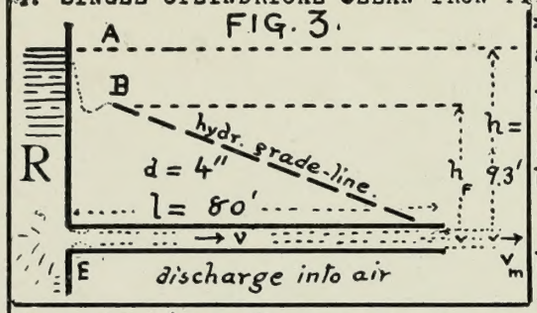


4. SINGLE CYLINDRICAL CLEAN IRON PIPE. NO NOZZLE (so that v_m, veloc of jet = v, vel. in pipe). Given l, d, and h, we are to find v and Q. By Bern's Theor.,

$$h = \zeta_E \frac{v^2}{2g} + h_F + \frac{v_m^2}{2g};$$

(see fig. for Hyd. Gr. Line and h_F.)



For a pipe of this (relative) length h_F will probably take up a large part of the whole head h, = 9.3 ft.

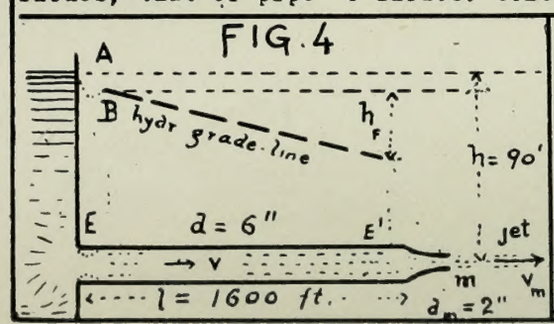
Assume, ∴, a trial value of 7 ft. for h_F. This is at rate of (7 ÷ 0.080 =) 87.5 ft. friction-head per 1000′ of pipe; from which (see diagram on opp. page) for a 4-inch pipe we find the veloc. in pipe would have to be v = 9.1′/sec. and (scale at upper edge of this page) $v_m^2 / 2g$ is noted to be 1.3 ft.; so that $\zeta v^2/2g = \frac{1}{2} \times 1.3$ = 0.65 ft.

To realize this trial value, 7′, for h_F, therefore, the whole head h would need to be 0.65 + 7 + 1.3, which = 8.95 ft. But this lacks 0.35 ft. of what it should be, viz., 9.3 ft. Hence assume h_F greater than 7′.

For the next trial value of h_F it will probably occasion no great error if the whole of this 0.35 be added to the first 7′. That is, assume h_F = 7.35 ft., which is at the rate of (7.35 ÷ 0.08 =) 92′ friction-head per 1000′ length. The diagram now gives v = 9.4′/sec. in 4-inch pipe and the veloc.-head scale, $v^2 \div 2g$ = 1.4 ft.; also 1/2 of 1.4 = 0.7 ft. Adding, 0.7 + 7.35 + 1.4 = 9.45 ft., which is so near to the given 9.3 ft. or h, that this second trial may be considered final. Hence (ANS.) we have $v_1 = v_m$ = 9.4 ft. per sec. and Q (from diagram) = 0.81 cub. ft./sec.

N.B. If the jet discharges under water the results are the same provided the surface of the water in the receiving reservoir is 9.3 ft. below that in the supply reservoir R (both reservoirs large)

5. SINGLE CYLINDRICAL (CLEAN) IRON PIPE; WITH NOZZLE (or play-pipe), jet discharging into the air with velocity v_m, to be found. Diam. of jet is 2 inches, that of pipe 6 inches. SOLUTION:— Here we note that the veloc. v, in pipe, is only 1/9 of that, v_m, in the jet, since the sectional areas are in this (inverse) ratio. From Bernoulli's Theorem we have



$$h = \zeta_E \frac{v^2}{2g} + h_F + \zeta' \frac{v_m^2}{2g} + \frac{v_m^2}{2g};$$

where h = 90 ft.; ζ_E = .50, = $\frac{1}{2}$; ζ' = .05, = $\frac{1}{20}$ (rounded nozzle, or conical play-pipe). Note that h is made up of four terms or "heads", of which the friction-head h_F in pipe is not necessarily a large item because v is small compared with v_m. Solve by diagram (opp. page) with successive trial values of some unknown quantity, say v. FIRST assume v = 5 ft./sec., for which from the diagram (for 6-inch pipe) we find the friction-head would be at the rate of 18′ per 1000′ of length, and hence h_F would be $\frac{1600}{1000}$ of 18, = 28.8 ft. From veloc.-head scale (above), since v = 5 and v_m = 9 × 5 = 45, we obtain $v^2/2g$ = 0.40 ft. and $v_m^2/2g$ = 31.4 ft. Hence the two small losses of head would be ½ of 0.4, = 0.2; and $\frac{1}{20}$ of 31.4, = 1.57 ft. The sum of these is

0.2 + 28.8 + 1.57 + 31.4, = 61.97 ft.; (but it should be 90 ft.)

SECOND TRIAL. Take v = 6 ft./sec. v_m would be 54 ft./sec., and the two veloc.-heads would be 0.56 and 45 ft.; hence the two small losses of head 0.28 and $\frac{1}{20}$ of 45, = 2.25 ft. Now 6 ft./sec. in a six-inch pipe implies a friction-head at rate of 25′ per 1000′ of length (diagram opp.) and ∴ h_F would be $\frac{1600}{1000}$ of 25, = 40 ft. Forming the sum, we have

0.28 + 40 + 2.25 + 45 , = 87.53 ft., the difference between which and 90′ is so small that a value of 6.1 ft./sec may be considered as a final solution for v; from which follow the values 55 ft./sec. for v_m and (see diagram) 1.2 cub. ft./sec. for the discharge, Q; ANS.

With increasing age the discharge (and v) would of course gradually diminish unless the pipe were kept clean. If the entrance E were rounded, a slight increase of Q would result.

6. VARIATION IN THE LAST PROBLEM. Instead of the diameter of the pipe being given, let us inquire what should be its value in order that 80′ of the total 90′ head may be available to produce the jet velocity v_m; that is, that only 10′ of the 90′ may be lost in friction-head and the two entrance losses of head; the remainder, 80′, being = $v_m^2/2g$. In this case, v_m itself would be (see scale above) 71.8 ft./sec.

At E′ the loss of head would be $\frac{1}{20}$ of 80′; i.e. 4′; while that at E may be neglected This leaves 10 − 4 , = 6 ft., for h_F, which is at the rate of (6/1.6 =) 3.75 ft. per 1000′ of length. Now a jet of 71.8 ft./sec. veloc. and of 2″ diam. is discharging Q = 1.56 cub. ft./sec. [obtained by multiplying 71.8 by the area (sq. ft.) of a 2″ circle; or, more simply, by diagram opp. (one quarter of 71.8 is 18 (say) which is within the limits of diagram and for a 2″ area gives Q = 0.39, which multiplied by 4 = 1.56)]

With the 3.75 and Q = 1.56 we find from diagram on p. 4 that a diameter of 9.9 inches (say 10 in.) must be given to the pipe in Fig. 4. *ANS.*

This change of design calls for a greater consumption of water (1.56 instead of 1.20 c.ft./sec.) but the "KINETIC POWER" (i.e., kinetic energy of the mass flowing per sec.) $[Q\gamma \div g] \times [v_m^2 \div 2]$ will be more than doubled. It will be 7800 instead of 3513 ft.-lbs. per sec.; i.e., 14.2 Horse Power instead of 6.4. (Kinetic power of the jet is meant.)

CONVENIENT RULE. To reduce cub. ft. per sec. to millions of gallons per day of 24 hours multiply by 0.646; to gals. per min., mult. by 448.8.

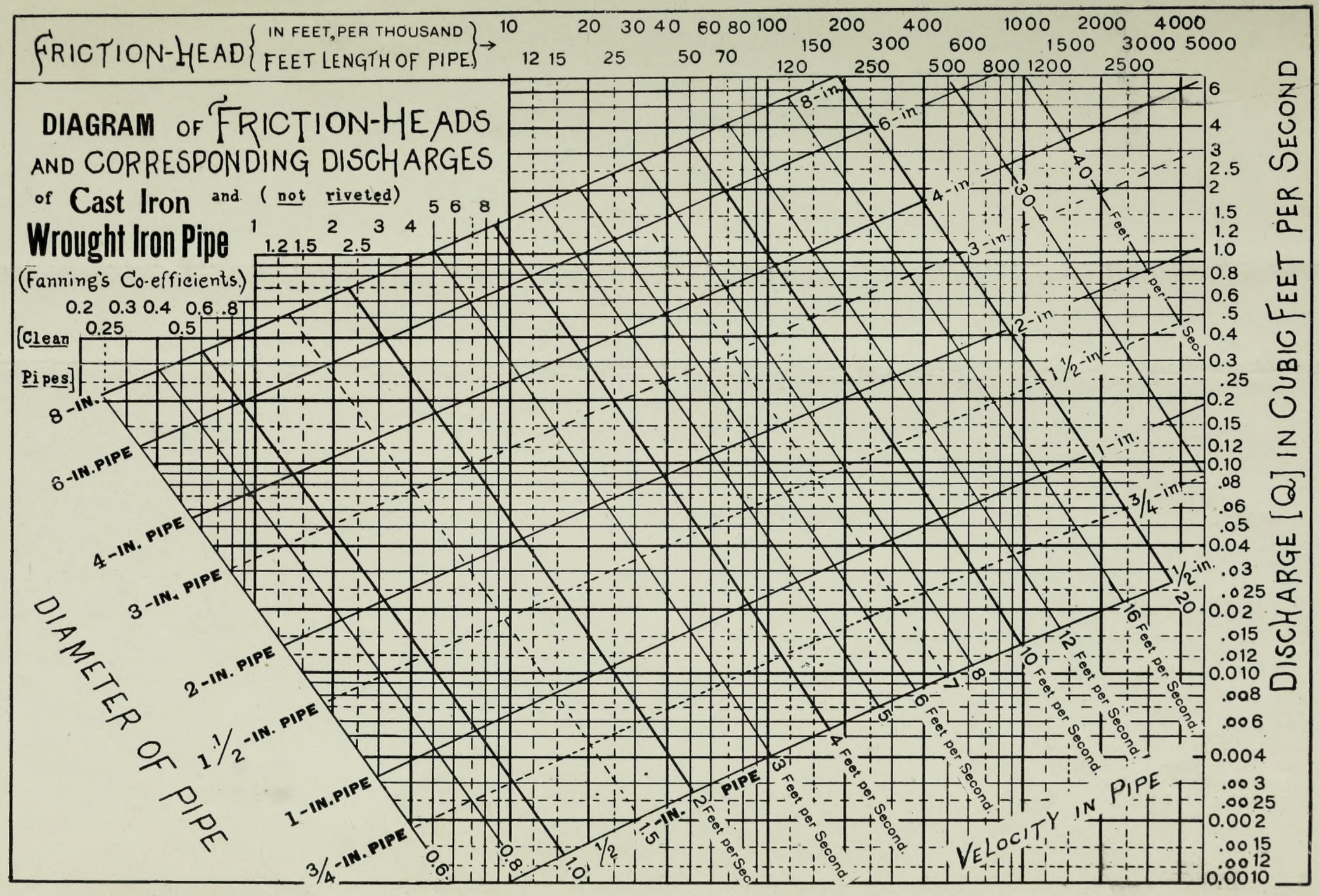
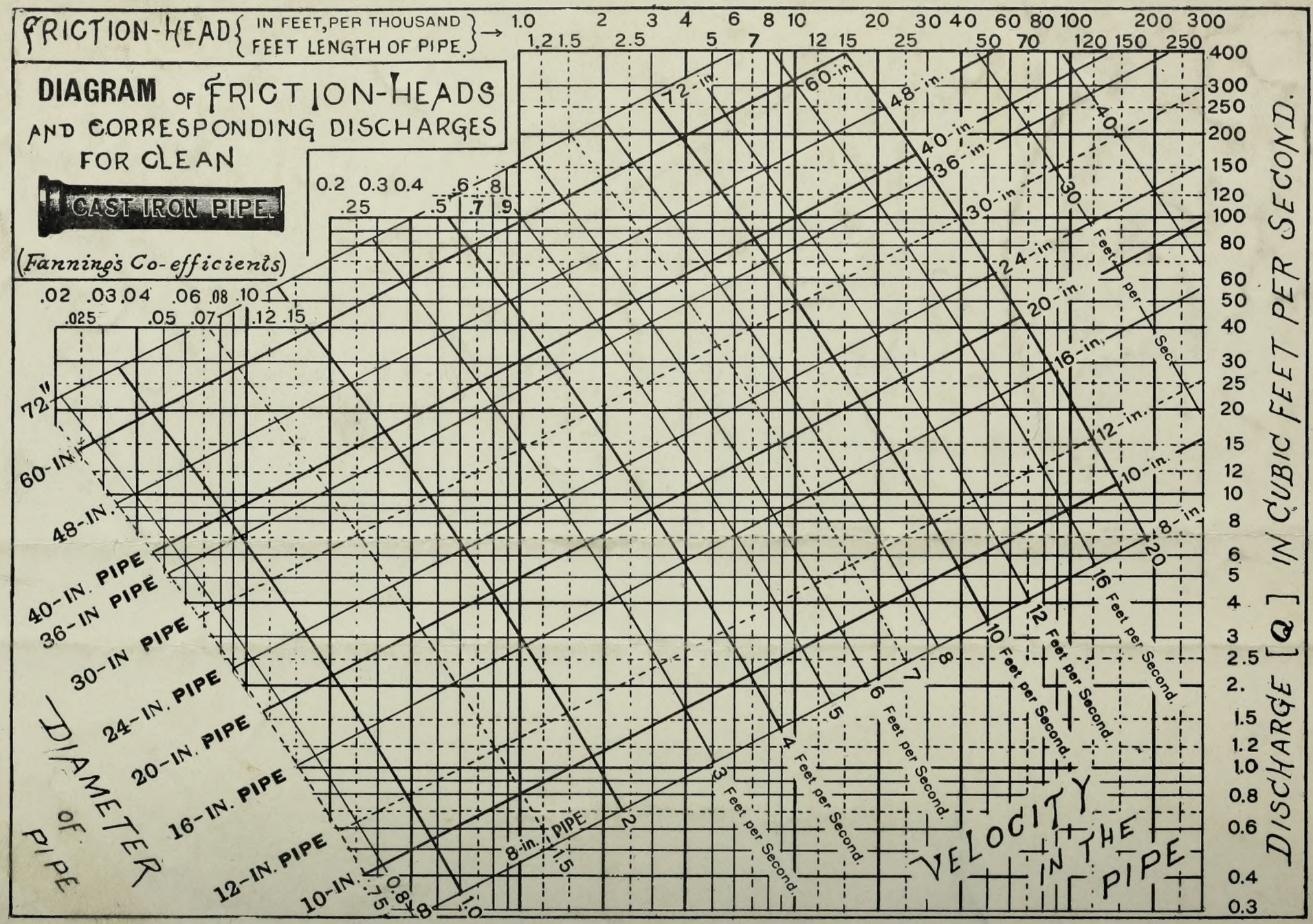


DIAGRAM OF FRICTION-HEADS AND CORRESPONDING DISCHARGES of Cast Iron and (not riveted) Wrought Iron Pipe
(Fanning's Co-efficients)
[Clean Pipes]
FRICTION-HEAD {IN FEET, PER THOUSAND FEET LENGTH OF PIPE}
DISCHARGE [Q] IN CUBIC FEET PER SECOND
DIAMETER OF PIPE
VELOCITY IN PIPE
8-IN.
6-IN. PIPE
4-IN. PIPE
3-IN. PIPE
2-IN. PIPE
1½-IN. PIPE
1-IN. PIPE
¾-IN. PIPE
½-IN. PIPE
2 Feet per Sec.
3 Feet per Second
4 Feet per Second
5 Feet per Second
6 Feet per Second
7 Feet per Second
8 Feet per Second
10 Feet per Second
12 Feet per Second
16 Feet per Second
20 Feet per Sec.



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